APPENDIX A

DETAILS OF INDIVIDUAL CRACK ARRESTOR EXPERIMENTS

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The results of the crack arrestor experiments are presented in Table 4 and individually discussed in the following section. Included in each discussion is:

- A description of the pipe section and arrestor style tested,
- The test parameters (i.e., the size of the arrestors, the radial clearances between the pipe and the arrestors, the backfill, and the composition and pressure of the gas),
- Any special instrumentation used in the experiment such as high-speed movie cameras and/or pressure transducers,
- The fracture speeds, and
- The results of the experiment, i.e., whether or not the arrestor was able to arrest the fracture.

For convenience of analysis, the results are grouped according to the basic arrestor design: loose sleeve, tight sleeve, grouted sleeve, or toroidal arrestors.

Loose Sleeve Crack Arrestor Experiments

Experiment 79-1-1

The total pipe section in experiment 79-1-1 was a 22-foot length of 6-inch O.D. x 0.120-inch wall thickness mechanical tubing. The arrestors were 1.0-inch (L/D = 0.167) and 0.75-inch (L/D = 0.125) rings of 6.5-inch O.D. x 0.25-inch wall thickness mechanical tubing with the inside and outside surfaces machined such that the arrestor wall thickness was 0.125 inch and the radial clearance (on the basis of percent of radial clearance of the pipe radius) was 1.45 percent. There was no backfill present. The pipe was pressurized with nitrogen to 2330 psig and the fracture initiated with a shaped explosive charge. High speed movies were taken of the event. In the direction of the 1-inch arrestor the fracture split and rang-off and hence failed to reach the arrestor. Similar bifurcations occurred in small diameter pipe experiments at the British Gas Council[A-1]. The 3/4-inch arrestor on the opposite side of the fracture origin arrested the fracture. The fracture speed into the 3/4-inch arrestor was estimated from the movies to be 635 feet per second (fps). The average circumferential strain at the front, middle, and back of the 3/4-inch arrestor was measured to be 3.8, 1.7, and 1.0 percent, respectively.

Experiment 79-1-2

The total pipe section in experiment 79-1-2 was a 22-foot length of 6-inch O.D. x 0.120-inch wall mechanical tubing. The arrestors were similar to those in experiment 79-1-1 except the lengths were 0.5 inch (L/D = 0.083) and 0.375 inch (L/D = 0.0625). The arrestors were the same thickness with the same radial clearance as in the previous test. There was no backfill. The pipe was pressurized with nitrogen to 2330 psig and the fracture initiated as in experiment 79-1-1. High speed movies were taken of the fracture event. The fracture broke and propagated past both arrestors. The fracture speeds were 410 fps into the 0.5-inch arrestor and 385 fps into the 0.375-inch arrestor.

Experiment 79-1-3

The total pipe section in experiment 79-1-3 was a 22-foot long section of 6-inch O.D. x 0.120-inch wall mechanical tubing. The arrestors were 1.0-inch (L/D = 0.167), 2.0-inch (L/D = 0.333), 3.0-inch (L/D = 0.5), and 4.0-inch (L/D = 0.667) rings of 7.0-inch O.D. by 0.25-inch wall thickness mechanical tubing with the outside surface machined such that the arrestor wall thickness was 0.125 inch and the radial clearance between the arrestor and pipe was 8.33 percent. The 1.0- and 3.0-inch arrestors were on one side of the fracture origin and the 2.0- and 4.0-inch arrestors were on the other side. There was no backfill. The pipe was pressurized with nitrogen to 2330 psig and the fracture initiated with a shaped explosive charge. In the direction of the 2.0- and 4.0-inch arrestors the fracture bifurcated and failed to reach the arrestors. The fracture in the other direction, propagating at 618 fps, propagated under both the 1.0- and 3.0-inch arrestors.

Experiment 6-1

The pipe section tested in experiment 6-1 had a total length of 60 feet with a 19-foot long center test section of 6-inch (6 5/8-inch O.D.) X65 pipe with a 0.122-inch wall thickness. Two arrestor rings, 1-5/8 inches long (L/D = 0.245), were machined from larger diameter pipe such that the arrestor thickness was 0.120 inch and the radial clearance was 1.45 percent. The pipe was pressurized with a 16 percent propane and 84 percent nitrogen mixture to 2300 psig. The gas temperature was +55 F. The rationale for using the propane/nitrogen mixture was that the gas would decompress from the gas phase into the two-phase region. This produces a higher crack driving force than the nitrogen environment. This higher crack driving force better simulated the crack driving force associated with a pipeline used to transport natural gas with heavy hydrocarbons such as ethane or propane. In both directions the fracture was arrested by the arrestors. The fracture speeds were 635 fps on the south end of the pipe and 533 fps on the north end of the pipe.

Experiment 6-2

The pipe section tested in experiment 6-2 had a total length of 60 feet with a 19-foot long center test section of 6-inch (6-5/8-inch O.D.) X65 pipe with a 0.122-inch wall thickness. Two arrestor rings, 7/8 inch long (L/D = 0.132), were machined from larger diameter pipe such that the arrestor thickness was 0.120 inch and the radial clearance was 1.45 percent. The pipe was pressurized with a 16 percent propane and 84 percent nitrogen mixture to 2000 psig. The gas temperature was +55 F. The 7/8-inch arrestor on the south end of the pipe arrested the fracture.

The fracture speed was 460 fps. On the north side, the crack arrested before reaching the 7/8-inch arrestor.

Experiment 6-3

The pipe section tested in experiment 6-3 was a 19-foot length of 6-inch (6 5/8-inch O.D.) X65 pipe with a 0.122-inch wall thickness. The two arrestors used in this experiment were identical in size. These were 1/2-inch (L/D = 0.075) rings machined from larger diameter pipe such that the arrestor thickness was 0.120 inch and the radial clearance 1.45 percent. The pipe was pressurized with a 12 percent propane and 88 percent nitrogen mixture to 2300 psig. The gas temperature was + 25 F. At the lower gas temperature the different gas composition produced similar decompression characteristics as in experiment 6-1. The fracture broke and propagated past the arrestor on the south end of the origin; the fracture speed was 740 fps. On the north end the fracture was arrested by the arrestor; the fracture speed on this end was 367 fps. The different fracture speeds were due to backfill conditions being different on the two sides of the origin.

Experiment 12-1

The pipe tested in experiment 12-1 was a 31-foot length of 12-inch (12 3/4-inch O.D.) X65 pipe with a 0.226-inch wall thickness which was in the center of a 60-foot long pipe section. The arrestors were 0.80-inch (L/D = 0.063) and 4.0-inch (L/D = 0.314) rings machined from larger diameter pipe such that the arrestor thicknesses were 0.50 inch and the radial clearances were 1.96 percent. Both sizes of arrestors were on each side of the fracture origin. The pipe was pressurized to 1805 psig. The composition of the gas was 12 percent propane, 84 percent nitrogen, and 4 percent oxygen. A small amount of oxygen was present since it was necessary to use an air compressor to reach the final pressure. The gas temperature was + 26 F. The fracture, with a speed of 906 fps, broke the first arrestor and propagated under the second arrestor on the south end of the pipe. On the other end, the fracture broke the first arrestor and was arrested by the second arrestor; the fracture speed on this end was 731 fps.

Experiment 12-2

The pipe tested in experiment 12-2 was a 30-foot length of 12-inch (12 3/4-inch O.D.) X65 pipe with a 0.227-inch wall thickness which was in the center of a 60-foot long pipe section. On the north end of the pipe, the sole arrestor was a 0.8-inch (L/D = 0.063) ring machined from a larger diameter of pipe such that the arrestor thickness was 0.5 inch and the radial clearance was 1.96 percent. On the south end of the pipe, three arrestor rings, 0.8 inch (L/D = 0.063), 1.2 inches (L/D = 0.094), and 6.0 inches (L/D = 0.471), were machined from a larger diameter pipe such that the arrestor thicknesses and radial clearances were the same as for the arrestor on the north end of the pipe. The pipe was pressurized with a 10 percent propane and 90 percent nitrogen mixture to 1600 psig. The gas temperature was + 26.5 F. On the south end of the pipe, the fracture, with a fracture speed of 782 fps, propagated under the first two arrestors and was arrested by the third. On the north end of the pipe, the fracture was arrested by the sole arrestor; the fracture speed was 446 fps.

Experiment 80-10

The total pipe section in experiment 80-10 was a 22-foot length of 6-inch O.D. x 0.125-inch wall thickness mechanical tubing similar to that tested in experiments 79-1-1, 79-1-2, and 79-1-3. The arrestors were 3.5-inch (L/D = 0.583), 4.75-inch (L/D = 0.793), 6-inch (L/D = 1.00), and 7-inch (L/D = 1.17) rings of 7.2-inch x 0.25-inch wall thickness mechanical tubing with the outside surface machined such that the arrestor wall thickness was 0.125 inch and the radial clearance was 8.33 percent. The 3.5- and 6.0-inch arrestors were on one side of the fracture origin and the 4.75- and 7.0-inch arrestors were on the opposite side. There was no backfill. The pipe was pressurized with nitrogen to 2330 psig and the fracture initiated with an explosive cutter. The fracture propagated in both directions under the first arrestor, and was arrested by the reflected pressurization wave prior to reaching the second arrestor. The fracture speed through the first arrestors was 508 fps.

Experiment 80-11

The pipe section in the experiment 80-11 was a 22-foot length of 6-inch O.D. x 0.125-inch wall mechanical tubing. The arrestors were 2.5-inch (L/D = 0.417) and 3.5-inch (L/D = 0.583) rings of 6.5-inch O.D. x 0.25-inch wall thickness mechanical tubing with the inside surface machined such that the wall thickness was 0.125 inch and the radial clearance was 4.0 percent. There was no backfill. The pipe was pressurized with nitrogen to 2400 psig and the fracture initiated with an explosive cutter. The fracture propagated under the 2.5-inch arrestor and was arrested by the 3.5-inch arrestor. The fracture speeds were 525 fps into the 2.5-inch arrestor and 560 fps into the 3.5-inch arrestor.

Experiment 80-12

The total pipe section in experiment 80-12 was a 23-foot length of 6.0-inch O.D. x 0.125-inch wall mechanical tubing. The arrestors were 6.0-inch (L/D = 1.00), 7-inch (L/D = 1.17), and 10-inch (L/D = 1.67) rings of 7.0-inch O.D. x 0.25-inch wall thickness mechanical tubing with the outside surface machined such that the arrestor wall thickness was 0.125 inch. The radial clearance was 8.33 percent. The 6.0- and 10.0-inch arrestors were on one side of the fracture origin and the 7.0-inch arrestor was on the opposite side. There was no backfill. The pipe was pressurized with nitrogen to 2400 psig and the fracture initiated with a shaped explosive charge. The fracture propagated under and past each of the arrestors without breaking the arrestors. The fracture speeds were 835, 800, and 800 fps into the 6.0-, 7.0-, and 10.0-inch arrestors, respectively.

Experiment 80-18

The pipe in experiment 80-18 was a 26-foot length of 12-inch (12.75-inch O.D.) X65 line pipe with a 0.223-inch wall thickness which was centered in a 60-foot long pipe section. Three arrestors were machined from 14-inch O.D. x 0.564-inch wall thickness pipe such that the arrestor wall thickness was 0.278 inch and the radial clearance was 3.92 percent. The lengths of the arrestors were 7.25 inches (L/D = 0.569), 8.75 inches (L/D = 0.686), and 10.87 inches (L/D = 0.853). Three other arrestors were machined from 14 3/8-inch O.D. x 0.507-inch wall thickness pipe such that the arrestor thickness was 0.311 inch and the radial clearance was 8.00 percent. The lengths of these arrestors were 15.0 inches (L/D = 1.16), 16.87 inches (L/D = 1.32), and 19.94 inches (L/D = 1.56). The arrestors with the 3.92 percent and the 8.00 percent radial clearances were on the opposite sides of the fracture origin. The pipe was backfilled with sand 3 feet above and 5 feet on each side of the pipe. The pipe was pressurized with a mixture of nitrogen and propane (84 percent nitrogen and 16 percent propane) to 2000 psig and the fracture initiated with a shaped explosive charge. The gas was circulated while injecting the propane to ensure a uniform mixture. The nitrogen/propane mixture produced a higher crack driving force than the pure nitrogen environment and was used to better simulate the decompressed pressure relationship and, thus, crack driving force associated with a transmission pipeline used to transport rich natural gas. Four pressure transducers were attached to the pipe to measure the decompressed pressure of the gas in the pipe at the crack tip. Two miniature transducers were attached to the pipe 5 feet from the fracture origin and two 1/4-inch pressure transducers were attached to the pipe 10 feet and 15 feet from the fracture origin. The crack propagated underneath all six of the arrestors. The fracture speed into each of the 3.92 percent radial clearance arrestors was 708 fps. The fracture speed into the first 8.0 percent radial clearance arrestor (L = 15.0 inches) was 833 fps; the fracture speed into the remaining two 8.0 percent radial clearance arrestors was 787 fps.

Experiment 80-20

The pipe tested in experiment 80-20 was a 30-foot length of 12-inch (12 3/4-inch O.D.) X65 line pipe with a 0.223-inch wall thickness which was centered in a 60-foot pipe section. The arrestors were split ring arrestors with spacer bars inserted in the splits of the arrestor sleeves. The split rings were made from sections of 12-inch X65 line pipe left over from test 80-19. The arrestor wall thickness was 0.223 inch and the spacer bar was sized such that the radial clearance was 4.0 percent for three arrestors and 2.87 percent for four arrestors. The lengths of the 4.0 percent radial clearance arrestors were 8.3 inches (L/D = 0.651), 12.75 inches (L/D = 1.00), and 16.0 inches (L/D = 1.25). The lengths of the 2.87 percent radial clearance arrestors were 4.4 inches (L/D = 0.345), 6.4 inches (L/D = 0.502), 8.3 inches (L/D = 0.651), and 10.2 inches (L/D = 0.800). The pipe was backfilled with sand. The pipe was pressurized with liquid carbon dioxide (CO_2) to 1200 psig at 80 F, and the fracture was initiated with a shaped explosive charge. The liquid CO_2 at 1200 psig and 80 F was just above the saturation line such that once the fracture initiated the pressure dropped slightly to the saturation pressure and remained at that relatively high pressure level while the CO_2 changed phases. This situation produced a very high crack driving force. As in test 80-18, four pressure transducers were attached to the pipe to measure the decompressed pressure of the fluid in the pipe at the crack tip. On the 4.0 percent radial clearance end of the pipe the fracture entered the 8.3-inch arrestor at 647 fps and propagated underneath. The fracture, with a fracture speed of 395 fps, was arrested by the second (12.75-inch) arrestor. On the 2.87-percent radial clearance end of the pipe the fracture broke the 4.4-inch arrestor and propagated under the 6.4-inch arrestor. The fracture speeds entering these arrestors were 655 and 415 fps, respectively. The third arrestor (8.3 inches) arrested the fracture. The fracture speed entering the third arrestor was 415 fps.

Tight Sleeve Crack Arrestor Experiment

Experiment 81-1

The pipe tested in experiment 81-1 was a 19-foot length of 6-inch (6 5/8-inch O.D.) X65 line pipe with a 0.123-inch wall thickness centered in a 60-foot long pipe section. The arrestors tested were split ring sleeve arrestors made from lengths of 6-inch X65 line pipe left over from previous experiments. The thickness of the arrestors was 0.123 inch and the spacer bars were sized such that the arrestors would fit tightly around the pipe, i.e., the radial clearance was 0.0 percent, but not prestrained against the pipe. The lengths of the arrestors were 0.165 inch (L/D = 0.025), 0.331 inch (L/D = 0.050), and 0.662 inch (L/D = 0.100). The 0.165-, 0.331-, and 0.662-inch arrestors were all on the same side of the fracture origin. The other side had four polyurethane grouted sleeve arrestors which will be discussed later. The pipe was backfilled with sand. As in test 80-18, the pipe was pressurized with an 84 percent nitrogen and 16 percent propane mixture to 2000 psig. Three pressure transducers were attached to the pipe 1.75, 4.75, and 8.25 feet from the fracture origin to measure the decompressed pressure of the gas in the pipe at the crack tip. The fracture was initiated with an explosive cutter. The fracture propagated into the 0.165-inch arrestor with a speed of 571 fps and broke the arrestor. The fracture was arrested by the second arrestor, L = 0.331 inch. The fracture speed into the second arrestor was 571 fps.

Grouted Sleeve Crack Arrestor Experiments

Experiment 81-1

The pipe tested in experiment 81-1 was a 19-foot length of 6-inch (6 5/8-inch O.D.) X65 line pipe with a 0.123-inch wall thickness centered in a 60-foot long test section. The arrestors were split ring, sleeve arrestors made from lengths of 6-inch X65 line pipe left over from previous crack arrestor experiments. The thickness of the arrestors was 0.123 inch and the spacer bars were sized such that the radial clearance was 1.5 percent. The space between the pipe and arrestor was filled with polyurethane foam. Attempts were made at keeping the space between the arrestor and pipe uniform. The lengths of the arrestors were 0.331 inch (L/D = 0.050), 0.662 inch (L/D = 0.100), 1.324 inches (L/D = 0.200), and 1.096 inches (L/D = 0.300). The arrestors were all on one side of the fracture origin. As discussed previously, the other side of the origin had the three tight sleeve arrestors. The pipe was backfilled with sand and pressurized with an 84 percent nitrogen and 16 percent propane mixture to 2000 psig.

The fracture was initiated with a shaped explosive charge. The fracture broke and propagated past the first two arrestors (L = 0.331 inch and L = 0.662 inch). The fracture speeds into the first two arrestors were 574 and 452 fps, respectively. The third arrestor (L = 1.324 inches) arrested the fracture. The fracture speed into the third arrestor was 309 fps.

Experiment 81-2

The pipe tested in experiment 81-2 was a 20-foot length of 6-inch (6 5/8-inch O.D.) X65 line pipe with a 0.123-inch wall thickness which was centered in a 60-foot long test section. The arrestors were split ring sleeve arrestors made from lengths of 6-inch X65 line pipe left over from previous crack arrestor experiments. The thickness of the arrestors was 0.123 inch and the spacer bars were sized such that the arrestor had a radial clearance of 4.0 percent. The lengths of the arrestors were 0.331 inch (L/D = 0.050), 0.662 inch (L/D = 0.100), 1.324 inches (L/D = 0.200), and 1.986 inches (L/D = 0.300). The space between the arrestors and pipe was filled with fast curing cement mortar. Attempts were made, while filling the void, to keep the space between the pipe and arrestors uniform. All of these arrestors were on one side of the fracture origin. The other side of the origin had four welded cold rolled toroidal arrestors which will be discussed later. The pipe was backfilled with sand and pressurized with an 84 percent nitrogen and 16 percent propane mixture to 2000 psig. Three pressure transducers, used to measure the decompressed pressure of the gas in the pipe at the crack tip, were attached to the pipe 1.75, 4.75, and 8.25 feet from the fracture origin.

The fracture was initiated with a explosive charge. The fracture broke and propagated through the first two arrestors. The fracture speeds into the first two arrestors were 630 and 545 fps, respectively. The third arrestor (1.324 inches long) arrested the fracture. The fracture speed into the third arrestor was 354 fps.

<u>Experiment 81-5</u>

The pipe tested in experiment 81-5 was a 30-foot length of 12-inch (12 3/4-inch O.D.) X65 pipe with a 0.224-inch wall thickness centered in a 60-foot long test section. A set of sleeve arrestors 2 inches (L/D = 0.157), 3 inches (L/D = 0.235), 4.5 inches (L/D = 0.353), and 6 inches (L/D = 0.471) in length were on each side of the fracture origin. One side of the origin the radial spacing was 4.0 percent, while on the other side the radial spacing was 8.0 percent. The annular spaces between the pipe and arrestors were filled with cement mortar. The pipe was backfilled with sand and pressurized with air to 2000 psig. The fracture was initiated with a shaped explosive charge. On both sides of the fracture origin, the fracture broke the first arrestor (L = 2.0 inches) and was arrested by the second arrestor (L = 3.0 inches). On the 4 percent radial clearance side of the origin, the fracture speeds were 793 and 512 fps into the first and second arrestors, respectively. On the 8 percent radial clearance side of the origin the fracture speeds were 852 and 679 fps into the first and second arrestors, respectively.

Toroidal Crack Arrestor Experiments

Experiment 80-19

The pipe tested in experiment 80-19 was a 29-foot length of 12-inch (12 3/4-inch O.D.) X65 line pipe with a 0.219-inch wall thickness which was centered in a 60-foot long test section. The arrestors were toroidal (i.e., donut shaped) arrestors made from hot rolled AISI 1018 round bar stock. The arrestor diameters were 0.75-inch (equivalent sleeve length*/pipe diameter (L/D = 0.158)), 0.875 inch (L/D = 0.215), 1.00 inch (L/D = 0.281), and 1.25 inches (L/D = 0.439). The hot rolled stock was rolled in a rolling machine into a ring, then fit to the pipe, and cut to the required length for the radial clearance specified for the test. The ends were then butt welded together. The actual inside diameters of the rings were measured at 4 locations around the pipe and averaged such that the actual average radial clearances could be determined. The actual radial clearances varied from 1.14 to 1.98 percent. Single ring toroidal arrestors were on one side of the fracture origin and double ring toroidal arrestors (two arrestors of the same size positioned next to each other with a 2-inch spacing between them) were on the opposite side. Two 1/4-inch pressure transducers, used to determine the decompressed pressure relationship in the pipe, were attached to the pipe 5 feet from the fracture origin on the side of the pipe with the single toroidal arrestors. The pipe was backfilled with sand and pressurized with air to 2000 psig.

The fracture was initiated with a shaped explosive charge. The fracture broke and propagated past the first single toroidal arrestor (0.75 inch) and was arrested by the second single toroidal arrestor (0.875 inch). The fracture speeds were 706 and 638 fps into the first and second arrestors, respectively. The first double toroidal arrestor (0.75 inch) arrested the fracture. The fracture speed was 851 fps.

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*Equivalent sleeve length for toroidal arrestor = $\pi(d_{tor})^2/4t_{pipe}$.

Experiment 81-2

The pipe tested in experiment 81-2 was a 20-foot length of 6-inch (6 5/8-inch O.D.) X65 pipe with a 0.123-inch wall thickness which was centered in a 60-foot pipe section. On one side of the fracture origin were four single toroidal arrestors fabricated from cold rolled bar stock. The other side of the origin had four cement grouted sleeve arrestors discussed earlier. The cold roll bar stock used had an ultimate strength approximately 20 percent higher than the hot rolled bar stock used in the previous toroidal crack arrestor experiment. The diameters of the toroidal arrestors were 0.314 inch (L/D = 0.095), 0.340 inch (L/D = 0.132 inch), 0.423 inch (L/D = 0.172), and 0.466 inch (L/D = 0.209). The arrestors were rolled, cut to length, butt welded together and slipped on the pipe as were the hot rolled arrestors in experiment 80-19. The radial clearance for the four arrestors averaged 1.6 percent. The pipe was backfilled with sand and pressurized with an 84 percent nitrogen and 16 percent propane mixture to 2000 psig.

The fracture was initiated with a shaped explosive charge. The propagating ductile fracture broke the first arrestor (0.314-inch diameter) and propagated past it. It was arrested by the second arrestor (0.370-inch diameter). The fracture speed into the first and second arrestors was 613 fps.

Experiment 82-1

The pipe in experiment 82-1 was a 30-foot length of 12-inch (12 3/4-inch O.D.) X65 line pipe with a 0.222-inch wall thickness. The arrestors were single ring toroidal arrestors with an in-line coupler. Both the arrestors and couplers were made from AISI 1018 cold rolled bar stock. The advantages of these arrestors were that they may be much easier and cheaper to install, and could be assembled to an in-service pipeline. The disadvantage in this particular design was that the manufacturing tolerances were small in that, if the two halves of the arrestors did not line up during assembly, the threads of the arrestor halves and couplers would bind, provided that they would go together at all. Prior to designing the arrestors, high speed tensile tests were conducted on the coupler to determine the required length of engaged threads to ensure minimal loss of load carrying capacity. The results of these high speed tensile tests indicated that the required length of engaged threads is approximately 0.8 times the arrestor diameter. These tests, however, did not simulate the bending that may occur in the arrestor.

The arrestor diameters were 0.375 inch (L/D = 0.039), 0.500 inch (L/D = 0.069 inch), 0.625 inch (L/D = 0.108), and 0.750 inch (L/D = 0.156). On one side of the fracture origin the single ring arrestors were positioned on bare pipe. On the opposite side of the origin multiple layers of tar paper were placed between the arrestors and the pipe. The tar paper simulated rock shield. The arrestors on both sides of the origin were fit snugly to the pipe or tar paper such that the radial clearance was 0.0 percent but the pipe was not prestrained at 0 psig. The pipe was backfilled with sand and pressurized with air to 2000 psig. The fracture was initiated with a shaped explosive charge.

The propagating ductile fracture propagated the entire length of the pipe. No arrestors were actually fractured, but the threads on each arrestor were stripped during the fracture event. This was attributed to the manufacturing tolerances and associated line-up problems addressed above (i.e., the threads may have been damaged during installation due to poor fit-up conditions). Another potential contributor to the failure of all the threaded connections may be due to the combined bending and tensile strains at the connection during the fracture event. On the bare pipe side the fracture slowed from 645 fps at the first arrestor to 490 fps at the last arrestor. On the tar paper side the fracture slowed from 690 fps at the first arrestor to 490 fps at the last arrestor. The results of this test demonstrated that a major redesign of the coupler was necessary.

Experiment 82-2

The test pipe in experiment 82-2 was a 29-foot length of 12-inch (12 3/4-inch O.D.) X65 line pipe with a 0.218-inch wall thickness. The arrestors were double ring toroidal arrestors with "silo clamp" style connecting blocks (see Figure 12). The arrestors were made from AISI 1018 cold roll bar stock. The advantage of these arrestors over the single ring toroidal arrestors with the in-line couplers is that the manufacturing tolerances are not as severe and the bending strains at the connector block are minimized. The assembly time was less than 5 minutes per arrestor for two men. The arrestor diameters tested were 0.375 inch (L/D = 0.039), 0.500 inch (L/D = 0.069), 0.625 inch (L/D = 0.108), and 0.750 inch (L/D = 0.156). The spacings between the double toroidal arrestors on the top of the pipe were 3.4, 4.5, 5.6, and 6.8 inches with the spacing increasing in proportion to the diameter of the toroidal arrestors. On one side of the fracture origin the double toroidal arrestors were positioned on bare pipe. On the opposite side of the fracture origin four layers of 0.029-inch thick tar paper were placed between the arrestors and the pipe. The tar paper simulated rock shield which would be used to protect the pipe coating during field installation. On both sides of the origin, the arrestors were fit snugly to the pipe such that the radial clearance was 0.0 percent, but the pipe was not prestrained at 0 psig. The pipe was backfilled with sand and pressurized with air to 2000 psig. The fracture was initiated with a shaped explosive charge.

On both sides of the origin, the fracture broke and propagated past the first two arrestors (0.375- and 0.500-inch diameters) and was arrested by the third arrestor (0.625-inch diameter). On the bare pipe side the fracture speeds were 769 fps into the first arrestor, 588 fps into the second, and 435 fps into the third. On the tar paper side, the fracture speeds were 742 fps into the first arrestor, 588 fps into the second, and 400 fps into the third.